

ATOMIC AND SOLID STATE PHYSICS

MEASUREMENTS OF DIELECTRONIC RECOMBINATION IN He^+ IONS

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Dielectronic recombination¹ (DR) is an atomic process occurring in electron-ion collisions when the capture of an electron is accompanied by the simultaneous electronic excitation of the ion, resulting in the formation of a doubly-excited intermediate state; subsequent de-excitation by photon emission completes the recombination of the ion. The resonant recombination and radiative stabilization mechanisms which constitute the DR process are shown schematically in Fig. 1 for a helium-like (i.e., two-electron) ion. The DR process, which is mediated by the electron-electron interaction, is just the inverse of an Auger transition, and hence is resonant for relative velocities corresponding to outgoing Auger-electron energies.

It is well-known that, over a broad energy range, DR can be the principal means by which free electrons recombine with ions; consequently, DR has been of fundamental interest for many years.² In addition, DR is important to astrophysical studies,³ to the development of nuclear fusion plasmas,⁴ and as an important diagnostic tool for ion-beam cooling in storage rings. Cross sections for DR have been calculated extensively, but only recently have good measurements of DR become available for testing the theoretical predictions (see Ref. 2).

New measurements for DR for He^+ ions have been conducted at IUUCF using the ion storage ring and electron cooler. The storage ring was used in a "single-pass" mode in which the ions circled the storage ring and passed through the intense electron beam in the cooler region. Those He^+ ions not undergoing recombination were deflected by a ring dipole magnet and collected in a Faraday cup. Thus, the storage ring was used simply as a beamline with the Cooler providing the electron "target." Events resulting in DR were detected from the yield of neutral He atoms formed in the cooler region. The He atoms emerged through a 0° exit port following the Cooler region and were counted with a large (2"-diameter active area) Si solid-state detector. Since the main He^+ beam was collected in a Faraday cup, the incident beam flux could be measured accurately, thereby permitting an accurate determination of the DR cross sections.

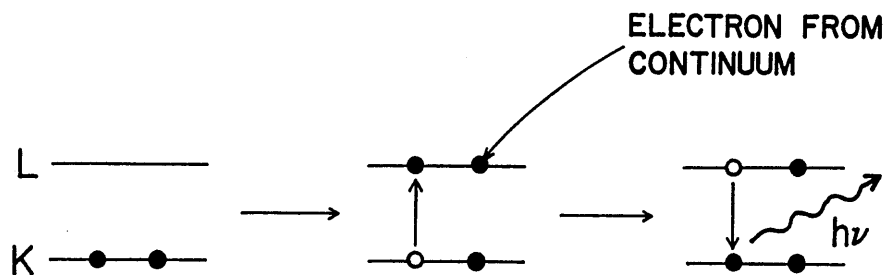


Figure 1. Schematic of the dielectronic recombination (DR) process for a two-electron (helium-like) ion.

For $\text{He}^+(1s)$ ions, DR is expected to occur for relative energies of 33–40 eV between the ion and electron. By ramping the relative electron energy through the range $|E_{\text{rel}}| = 0\text{--}50$ eV, DR could be investigated for electron velocities less and greater than the ion beam velocity. For $E_{\text{rel}} = 0$, a peak due to radiative recombination (RR) (inverse photoelectric effect) is expected.

Measurements were conducted for two different $^3\text{He}^+$ beam energies, 25 and 44 MeV; essentially the same results were obtained for both energies. Results for 44 MeV are shown in Fig. 2. The two regions labeled “DR” show resonances resulting from the electron beam moving slower ($v_e < v_i$) and faster ($v_e > v_i$), than the ion beam. The peak labeled “RR” ($v_e \simeq v_i$) is due to radiative recombination. RR occurs with highest probability for zero relative velocity between the ion and electron beams. In the laboratory frame, the observed peak energies were shifted due to the space charge of the dense electron beam inside the Cooler; the magnitude of the space charge effect was determined by recording spectra for various electron beam currents.

In the region of the DR maxima, clear structure due to individual DR resonances is discerned. The energy resolution in the rest frame of the ion was determined to be slightly less than 1 eV. Peaks associated with $n=2$, $n'=2$ intermediate states are seen at relative energies of 33 and 35 eV, and transitions involving intermediate states with $n=2$, $n'>2$ occur near 39 eV. An unexpected, broader peak near relative energies of 45 eV is believed to result from DR for $n, n' \geq 3$ intermediate states. In previous work^{5,6} at IUCF, insufficient energy resolution prevented observation of the structure resulting from the different n, n' configurations formed in the DR process.

From the present results, it has been determined that the major contributions to DR in He^+ come from $n=2$, $n'>2$ intermediate-state configurations, in agreement with theory,^{5,7} and the measured cross sections agree with the calculated ones to within about 20%. A more complete description of the present work can be found in Ref. 8.

In future work, measurements of DR for Li^+ ions are planned. An important consideration for Li^+ is the electron coupling which gives rise to angular momentum configurations different from those in He^+ , thereby providing more stringent tests of theoretical calculations than for He^+ . Beam time for this planned work with Li^+ has already been approved.

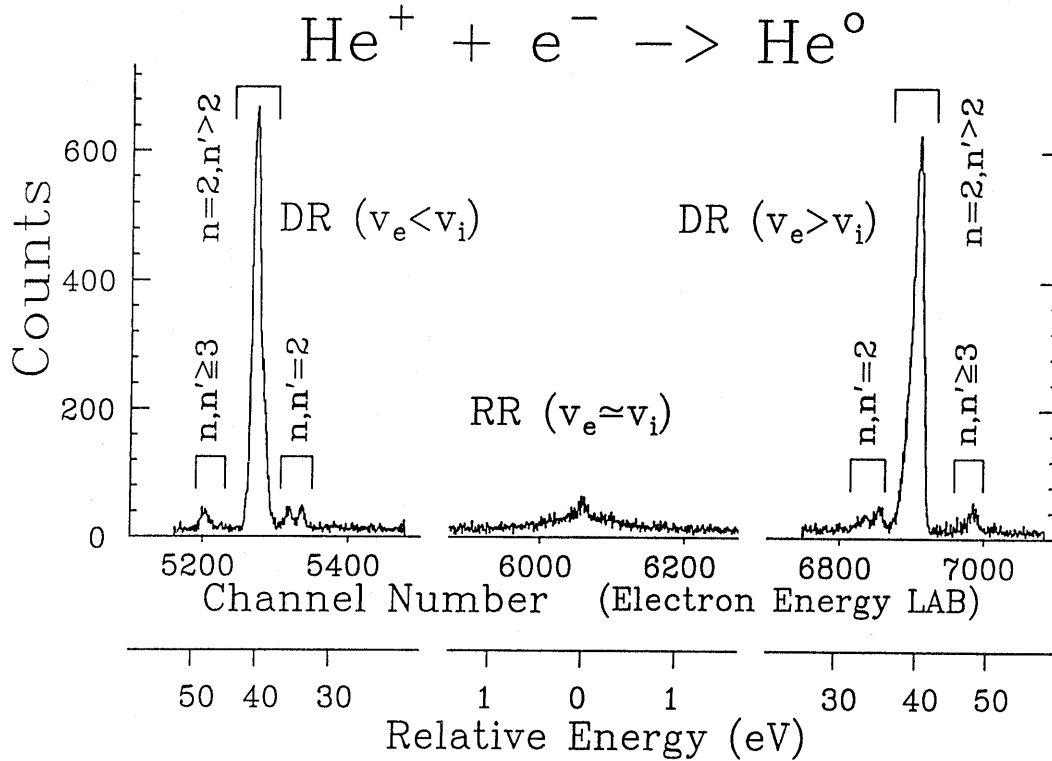


Figure 2. Yield of neutral He atoms formed in collisions of 44 MeV $^3\text{He}^+$ ions with electrons in the Cooler as a function of the laboratory electron energy (channel number in the figure) and the relative (in the projectile rest frame) electron energy. The energy resolution in the rest frame of the ion is less than 1 eV.

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